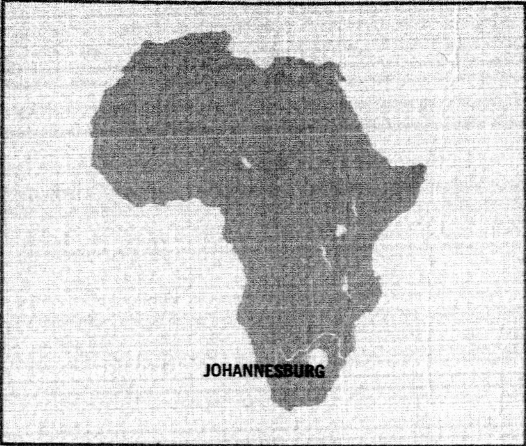
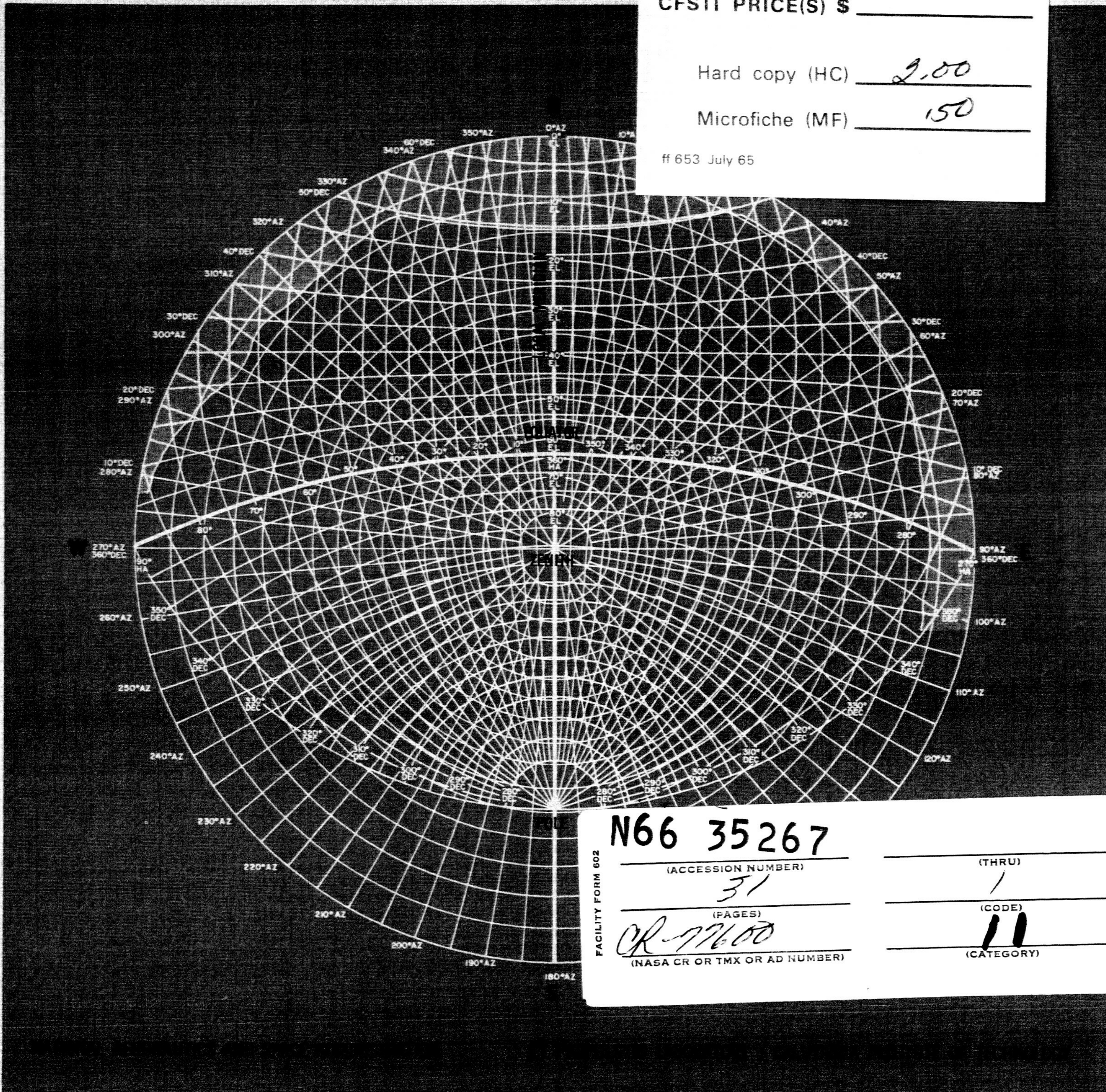


JPL TECHNICAL MEMORANDUM No. 33-224

DSIF: JOHANNESBURG



FRONT COVER: *A stereographic projection of the local coordinates used at the Johannesburg Station to define antenna-pointing angles for locating the spacecraft.*

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

JPL TECHNICAL MEMORANDUM No. 33-224

DSIF: JOHANNESBURG

JET PROPULSION LABORATORY / CALIFORNIA INSTITUTE OF TECHNOLOGY

Prepared Under Contract No. NAS 7-100
National Aeronautics & Space Administration

Foreword

A vital element in every National Aeronautics and Space Administration (NASA) space flight project is the communications system which returns data from the spacecraft to its home base and transmits instructions from Earth to the spacecraft. The Jet Propulsion Laboratory (JPL) pioneered the development of many of the critical elements of communications systems designed to function over the vast distance involved in cislunar and interplanetary missions. In 1958 the Laboratory first established a three-station network of receiving stations to gather the data from the first U.S. Earth-orbiter *Explorer I*. Since that time, the network has developed into the Deep Space Network (DSN) specifically designed to communicate with space probes traveling to the Moon and beyond.

The DSN has many outstanding accomplishments to its credit. Included among these are radar observations of several planets, tracking the *Mariner* missions to Venus and Mars, and receiving the television photographs from *Ranger*. The capabilities of the Network are continuously being improved in order to keep up with the demands of the more complex deep space missions undertaken by NASA.

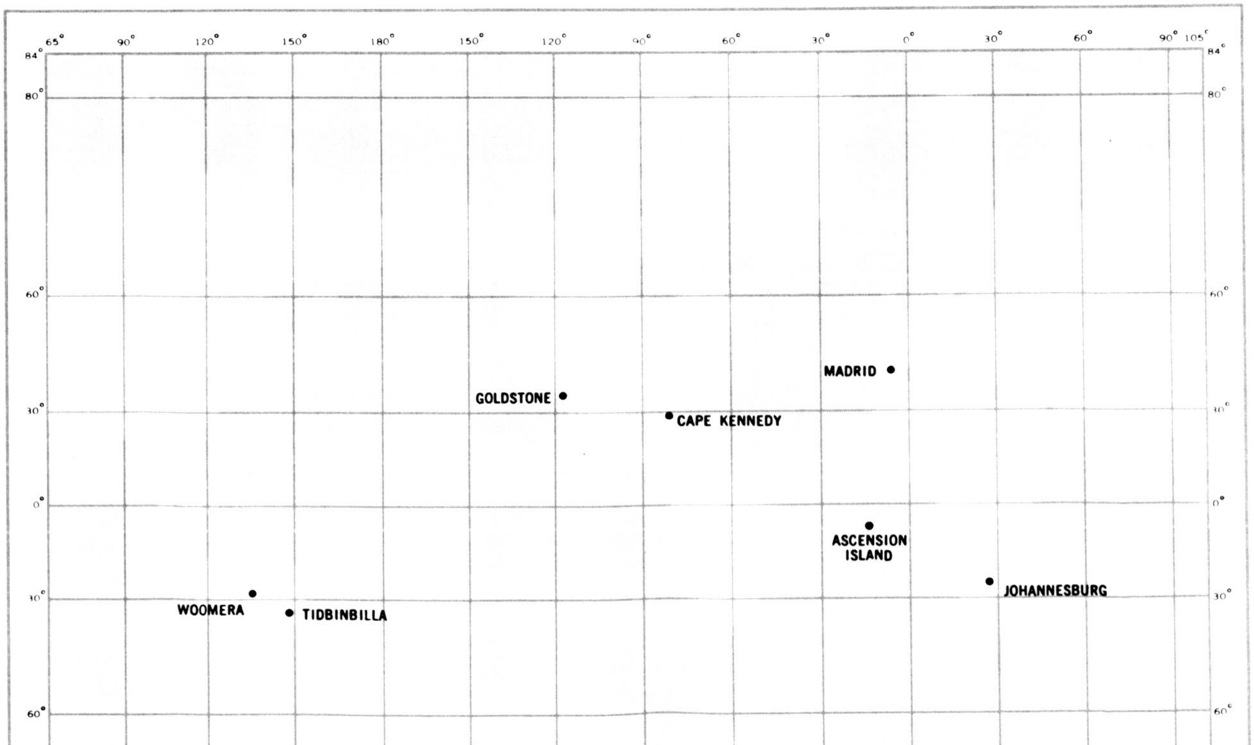
Since its establishment in 1961 the Johannesburg Station has been a vital link in the Deep Space Network. The success of the *Ranger* and *Mariner* programs would not have been possible without the capable participation of the staff at Johannesburg. We gratefully acknowledge the continued cooperation of the South African Council for Scientific and Industrial Research in this joint scientific project.

This Technical Memorandum is one of a series which describes the facilities and functions of the various major elements of the Deep Space Network.

W. H. Pickering

W. H. PICKERING
Director, Jet Propulsion Laboratory

DSIF stations circle the globe at intervals of 120 degrees in longitude to maintain continuous coverage of the spacecraft.



The Deep Space Network

One of several data-acquisition networks established by the National Aeronautics and Space Administration's Office of Tracking and Data Acquisition, the Deep Space Network is operated under the system management and technical direction of the Jet Propulsion Laboratory. The main elements of the DSN are the Deep Space Instrumentation Facility (DSIF), with space communication and tracking stations based around the world; the Space Flight Operations Facility (SFOF) at JPL in Pasadena, California, U.S.A., the command and control center; and the Ground Communications System, which connects all parts of the DSN by telephone and radio-teletype.

The DSIF stations are situated approximately 120 degrees apart in longitude so that the spacecraft is always within the field of view of at least one of the ground antennas. The DSIF locations are at Johannesburg, Republic of South Africa; Tidbinbilla and Woomera, Australia; Goldstone, California, U.S.A.; Madrid, Spain; and Ascension Island, South Atlantic Ocean. Support facilities include a spacecraft monitoring station at Cape Kennedy, Florida, U.S.A. JPL operates the U.S. stations and the Ascension Island station; the overseas stations are staffed and operated by government agencies of their respective countries.

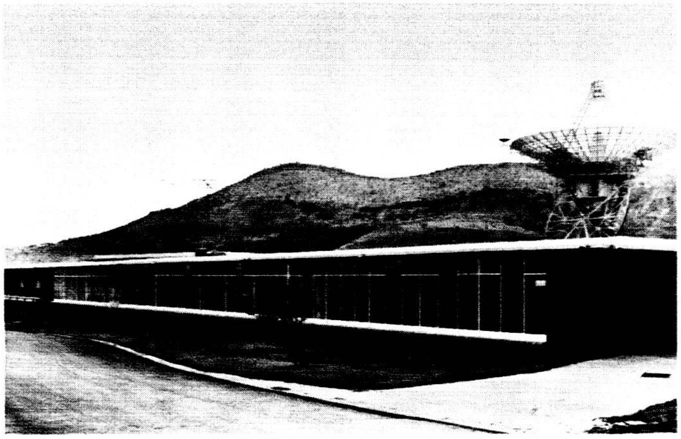
In addition to the Deep Space Network, NASA operates other spacecraft tracking facilities. These include the Scientific Satellite Network, which tracks Earth-orbiting scientific and communication satellites, and the Manned Space Flight Network, which tracks the manned spacecraft of the *Gemini* and *Apollo* programs. The DSN is designed for two-way communications with unmanned space vehicles with destinations more than 10,000 miles from Earth.

The Deep Space Network participated in the highly successful *Ranger* series of TV-picture-taking missions to the Moon, and in the *Mariner* flyby mission to Mars. In the near future the DSN will communicate with NASA's *Lunar Orbiter*, designed to obtain additional pictures of the Moon's surface, and with *Surveyor*, an advanced spacecraft that will land on the Moon. In coming years the DSN will take part in the *Voyager* program to explore the near planets.

The impact of space explorations is felt throughout the world, but most profoundly by those nations who actively participate in DSIF operations. They share in the trials and triumphs, as well as in the burden of spacecraft tracking, communication, and command that falls on the ground stations.

FACING: *The Johannesburg Space Communications Station is located in the foothills of the Magaliesburg, far from man-made noise that would interfere with the sensitive antennas.*

RIGHT: *Johannesburg operations and engineering building.*



Johannesburg Space Communications Station

The South African and United States Governments have entered into a cooperative agreement to establish and operate a station of the Deep Space Instrumentation Facility (DSIF) in the Republic of South Africa. The Johannesburg Space Communications Station is staffed by personnel of the National Institute of Telecommunications Research of the South African Council for Scientific and Industrial Research.

Each DSIF station is equipped with a polar-mounted 85-ft-diameter parabolic antenna and associated equipment for communicating with spacecraft millions of miles from Earth. The tracking stations must be located away from man-made electrical and commercial radio and television interference, and it is desirable that they be in natural bowl-shaped terrain to provide further shielding from interference.

A site fitting these requirements was found near the Hartebeestpoort Dam in the foothills of the Magaliesburg, about forty miles north of Johannesburg. The DSIF station is situated on farmland purchased by the South African Government for the establishment of a radio space research center. A station of the NASA-sponsored Satellite Tracking Facility is located nearby.

Johannesburg is the largest city of South Africa with a colorful history dating back to 1886. Early in that year one of the world's richest gold reefs was discovered beneath the bare Witwatersrand (Ridge of White Waters), and suddenly there appeared a huge dusty mining camp as fortune hunters from all over the world trekked to the new goldfields of the Transvaal Republic.

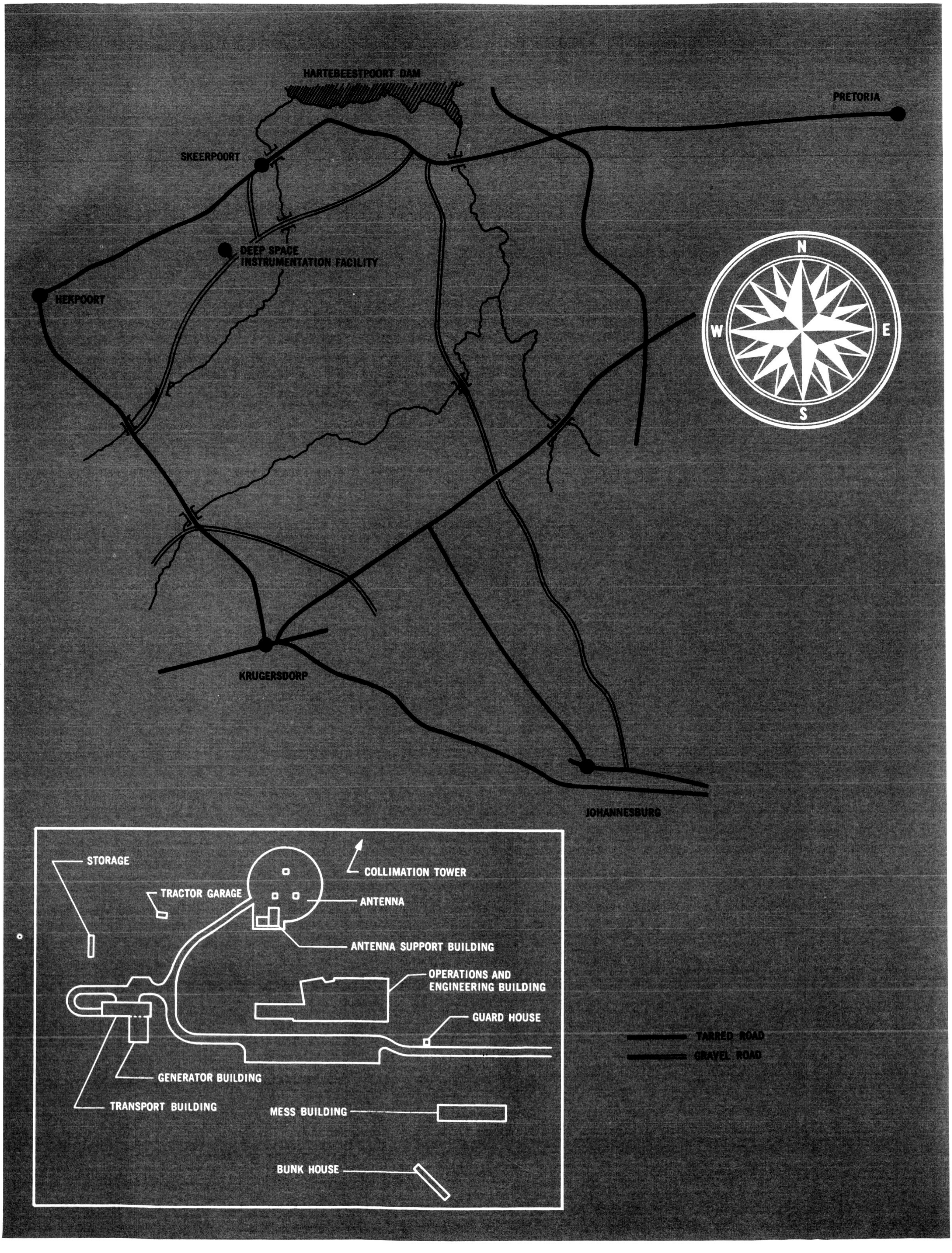
Today Johannesburg is the home of more than a million people and one of the most cosmopolitan cities on the continent of Africa. The Transvaal has become the most northern province of the Republic of South Africa. Gold mining is still a principal industry, but with the discovery of substantial coal deposits and the development of hydroelectric power on the Vaal River, a vigorous industrial complex is growing around Johannesburg.

A few miles north of Johannesburg is Pretoria, the capital of South Africa and the center of the diamond-mining industry. These two nearby cities offer rare cultural and recreational opportunities to the personnel of the DSIF station. Ballet, symphony concerts, live theatre, and art exhibits are presented regularly. Excellent restaurants and hotels are found in abundance.

Many organizations sponsor cricket, rugby, and tennis matches, and excellent boating is available at the nearby lake formed by the Hartebeestpoort Dam. Native culture is preserved in many museums and Bantu tribal dances are frequently presented at gold mines within the area. The Kruger National Park, about 225 miles east of Johannesburg, offers an unparalleled opportunity to observe the wild animals of Africa as they lived before the advent of man.

Johannesburg provides the DSIF station with nearby communications and transportation facilities which connect with all parts of the world. It is also a source of operating supplies and skilled construction and maintenance personnel, as well as being the home for many of the married workers and their families.

The Johannesburg Space Communications Station is one of the original links of the Deep Space Network and has played a vital part in a number of space programs since its establishment.


HARTEBEESTPOORT DAM
PRETORIA
SKEERPOORT
DEEP SPACE
INSTRUMENTATION FACILITY
HEKPOORT
N
W
E
S
KRUGERSDORP
JOHANNESBURG
STORAGE
COLLIMATION TOWER
TRACTOR GARAGE
ANTENNA
ANTENNA SUPPORT BUILDING
OPERATIONS AND
ENGINEERING BUILDING
GUARD HOUSE
TARRED ROAD
GRAVEL ROAD
GENERATOR BUILDING
TRANSPORT BUILDING
MESS BUILDING
BUNK HOUSE

FACING: *Map shows location of the Johannesburg DSIF, about 40 miles north of the city of Johannesburg. Inset shows station ground plan.*

The Station Manager and other key operating personnel performed acceptance tests on much of the electronic equipment when it was checked out at the Goldstone, California, station prior to shipment to Johannesburg. A DSN Resident Engineer from the Jet Propulsion Laboratory acts as a technical consultant to the Station Manager.

The major facilities at the station are:

a. An operations and engineering building which houses the majority of the tracking, telemetry, and communications equipment as well as laboratories and offices.

b. A utilities building which houses the power-generating and switching equipment, workshop facilities, and transport equipment.

c. The 85-ft-diameter antenna and an antenna support building which contains the hydro-mechanical equipment for the antenna and components of the final amplifier assembly for the radio transmitter.

d. A mess building which provides dining facilities for the staff of the station.

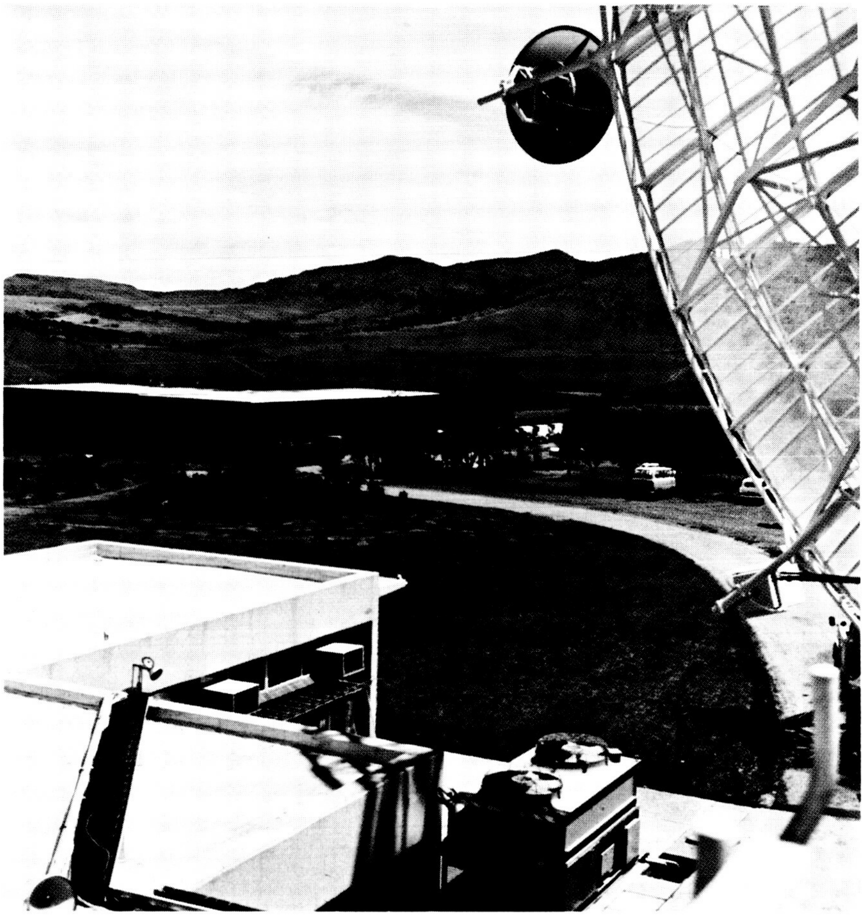
e. A bunk house which provides limited sleeping accommodations during 24-hour-a-day operations.

f. A collimation tower and a small building to house the collimation equipment located about two miles from the main antenna. A source of radio energy which simulates spacecraft signals is mounted in the collimation tower. This equipment is used to calibrate and check the performance of the main antenna and associated electronic systems.

In DSIF operations, Johannesburg performs the functions of *tracking*—locating the spacecraft, measuring its distance, velocity, and position, and following its course; *data acquisition*—gathering information from the spacecraft; and *command* — sending instructions from the ground that guide the spacecraft in its flight to the target, tell the spacecraft when to perform required operations and when to turn on the instruments for performing the scientific experiments of the mission. To aid in locating the spacecraft in early passes, the 85-foot antenna at Johannesburg is equipped with an auxiliary acquisition aid antenna that operates on a broad beam to pick up signals from the spacecraft in the general line of sight. Pointing information thus obtained is then transferred to the narrow-beam main antenna for pin-pointing spacecraft location.

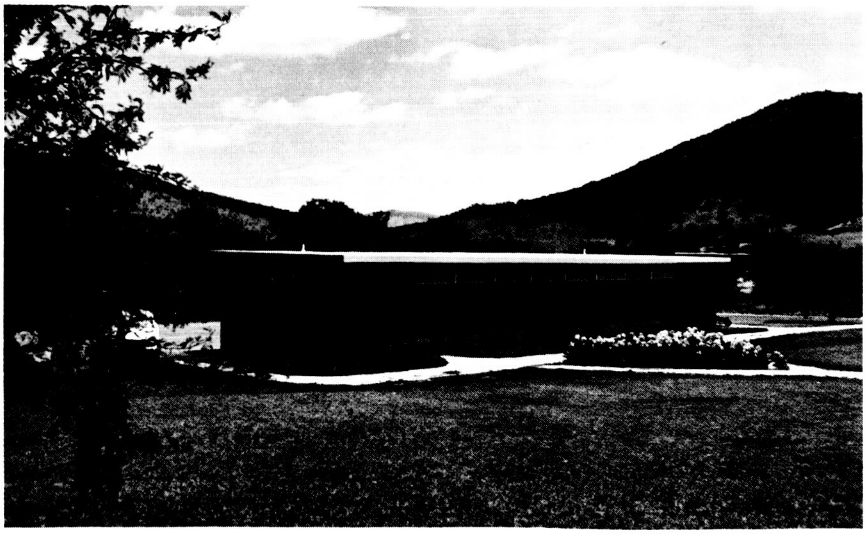
The station operates in the radio-frequency channels allocated to the DSIF, which until the completion of the *Ranger* series were in the L-band. Signals were transmitted to the spacecraft at 890 Mc (million cycles per second) and received from the spacecraft transponder at 960 Mc. Equipment has been modified to operate in the S-band for all future missions. Frequencies from 2110 to 2120 Mc are now used for transmission to the spacecraft, and from 2290 to 2300 Mc for information returned by the spacecraft.

Each space flight project requires equipment and accommodations unique to that project, dependent upon the type of command system to be used and the type of telemetry system the spacecraft will carry. Sometimes this may just mean a rearrangement of station equipment. When tailor-made equipment is required by a project, it is supplied to the station by the responsible project organization, and arrangements are made in advance for the equipment to be integrated with the normal complement of station equipment.

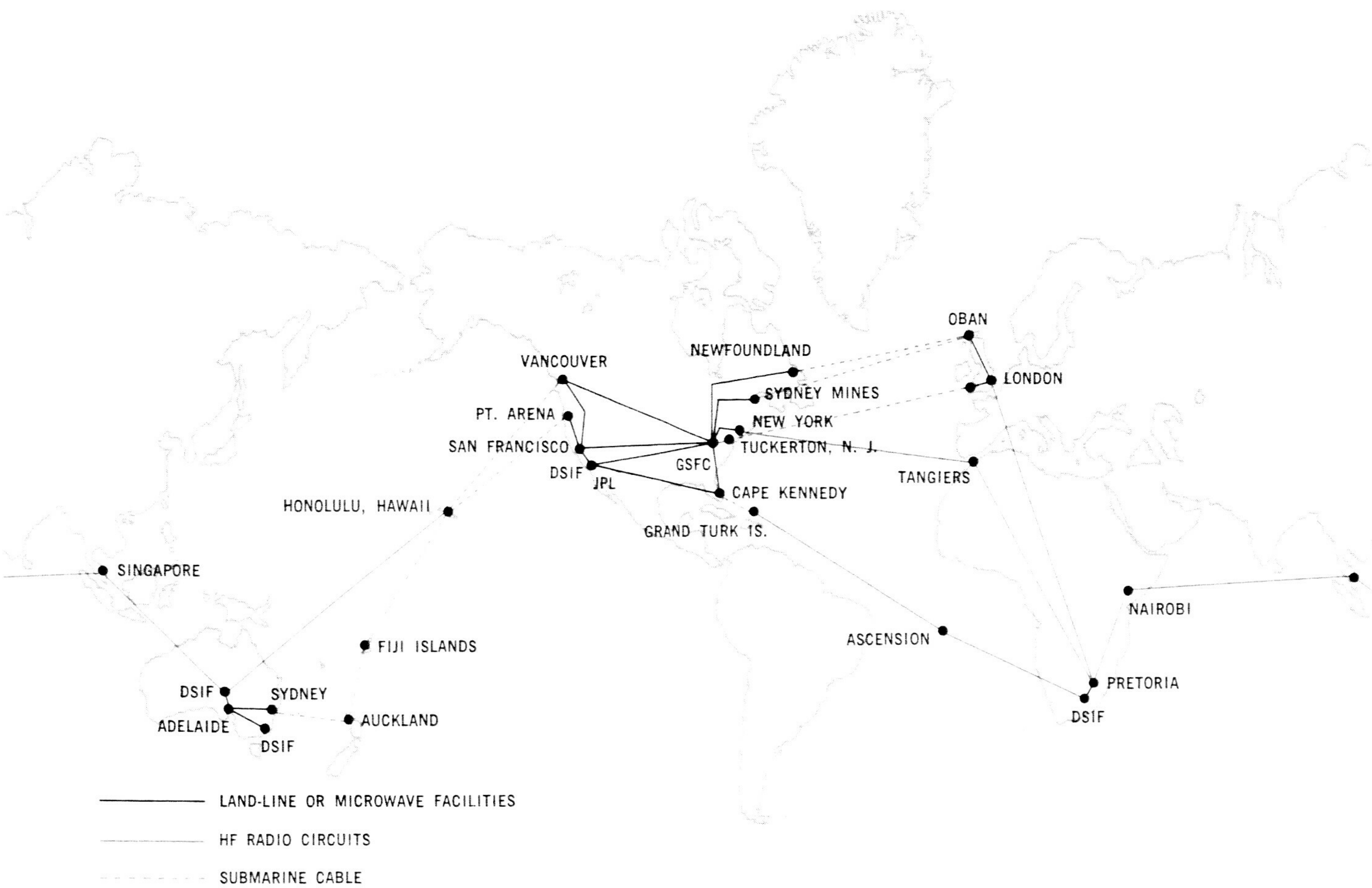


Hydromechanical building in foreground; transport and generator building in background.

Messing quarters.



Bunk house.



GEOGRAPHIC ROUTINGS OF LAND LINES, SUBMARINE CABLES, MICROWAVE AND HIGH-FREQUENCY RADIO CIRCUITS IN A TYPICAL NETWORK OF THE DSN GROUND COMMUNICATION SYSTEM.

Interstation Communications

Johannesburg has communication with other DSIF stations and the Space Flight Operations Facility (SFOF) at JPL by telephone and teletype through the DSN Ground Communication System, and is linked directly to the SFOF by high-speed teletype for digital data transmission via the Goddard Space Flight Center NASCOM system.

Teletype is the primary means used for transmitting tracking and telemetry data from the DSIF stations to the SFOF, and for sending predictions and other data to the stations. Analog and TV data channels may be available for some missions. Voice circuits are used for transmission of high-priority communications other than data.

Technical control of all communications facilities throughout the DSN is exercised by the Communications Coordinator in the SFOF.

Communications links to Johannesburg Station include three full duplex teletype circuits, one high-speed data circuit, and two voice circuits.

Teletype transmission is at the rate of 60 words per minute. On the high-speed data lines, Johannesburg can "talk" to computers at the JPL SFOF at the rate of 600, 1200, and 4400 bits per second (the 4400-bit rate is about equal to 8800 words per minute). On-site communications at Johannesburg are handled by telephone, local paging system, and closed-circuit TV.

FACING: *Large antennas designed to pick up the faintest of radio signals enable man to listen to messages relayed from space.*

Reaching Into Deep Space

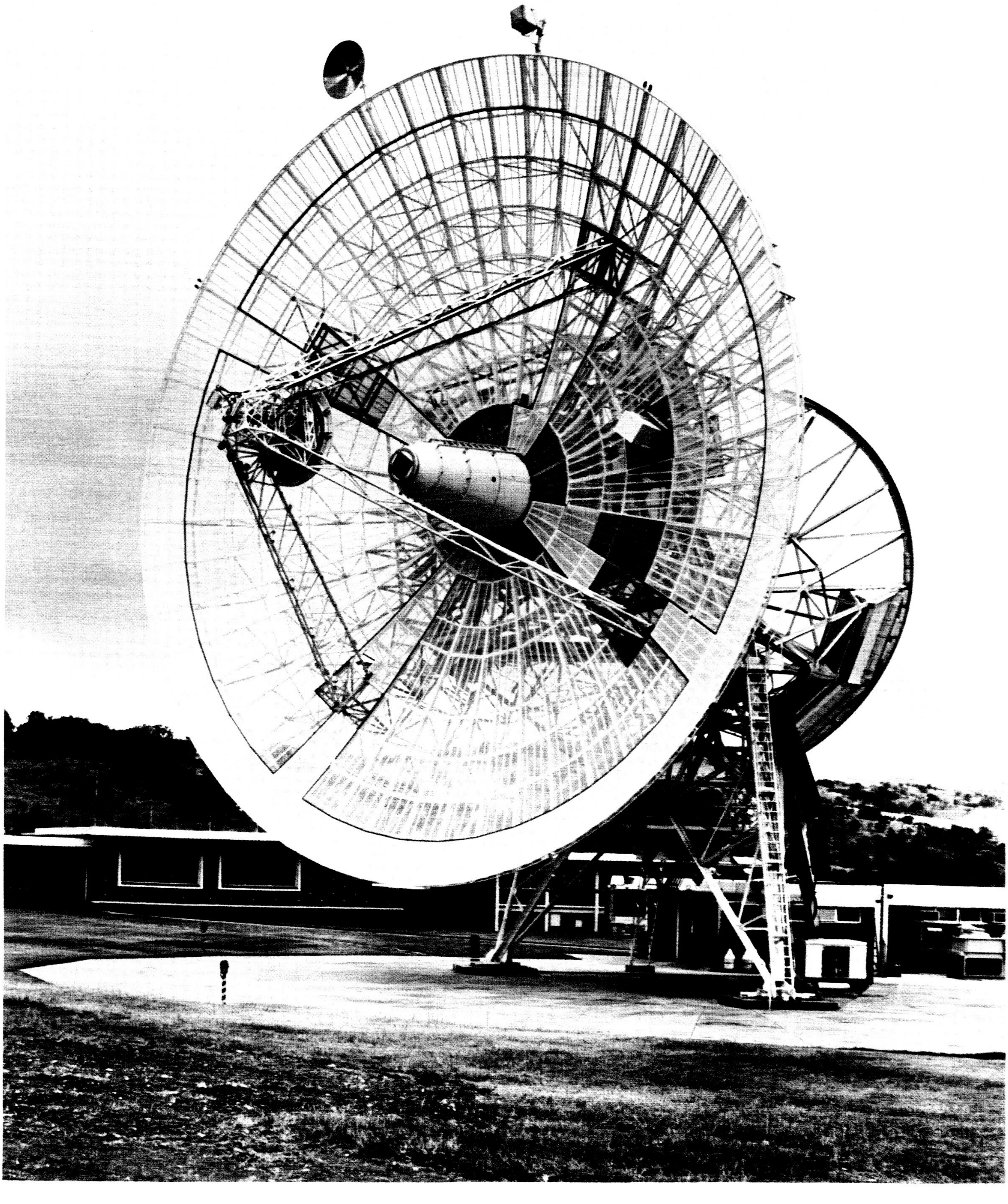
The only truly practical means known today of communicating with spacecraft at deep space distances is the same basic technology that brings radio and television into our homes — radiation of electromagnetic waves through space. The difference lies in the magnitude of the problem of how to overcome the great loss of energy of a signal that occurs because of the tremendous distances it must travel.

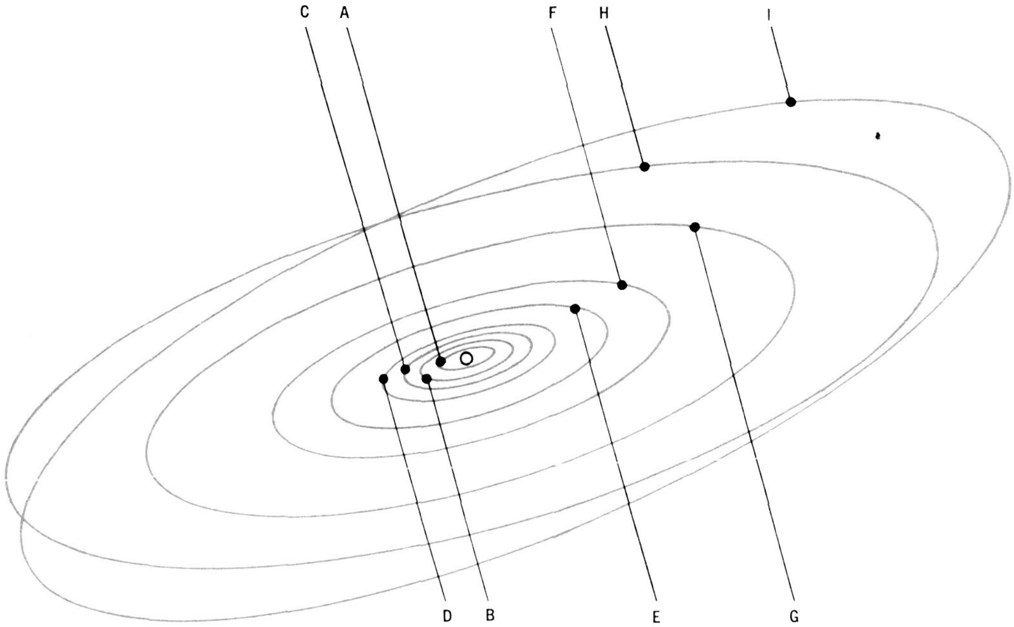
In the brief span of DSIF history, spectacular progress has been made in the evolution of antenna, receiver, and transmitter capabilities, which is fast approaching the technical and theoretical limits for communication within our solar system. Present technology is capable of meeting requirements for tracking, command, and data acquisition at distances ranging up to hundreds of millions of miles from Earth. Sophisticated communications techniques have developed so rapidly that by 1966 the DSIF capability, measured in quantity of information transmitted per unit of time, will have increased more than a thousand times over that of the pre-1960 capability.

To overcome space losses, the DSIF uses antennas designed for high gain, or very high concentration of received signal power, extremely low-noise radio amplifiers, and powerful transmitters that send out a very strong signal. Standard DSIF ground transmitters operate at power levels of 10 kilowatts (10,000 watts). A spacecraft transmitter, on the other hand, is very limited in power because of size and weight restrictions. Very early spacecraft (*Pioneer III*) used power outputs as small as 0.2 watt; the *Ranger IX* spacecraft used two 60-watt transmitters to send back to Earth the images recorded by the six television cameras. Continuing development will increase transmitter outputs for probes contemplated for exploratory missions to the edge of the solar system.

The well-known doppler principle has long been used in determining the relative speed with which a celestial body or star and the Earth are approaching or receding from each other (the radial velocity). The doppler shift is the apparent change in frequency of a signal reflected from or emitted by a moving object as the object moves toward or away from the observer — much as a train whistle is high in pitch as the train approaches, then lower in pitch as it passes.

The doppler principle has been adapted for use in determining spacecraft velocity. Early spacecraft used one-way doppler—measuring the difference between the





A. MERCURY	36,000,000
B. VENUS	67,000,000
C. EARTH	93,000,000
D. MARS	142,000,000
E. JUPITER	484,000,000
F. SATURN	886,000,000
G. URANUS	1,783,000,000
H. NEPTUNE	2,793,000,000
I. PLUTO	3,666,000,000

COMMUNICATION WITHIN OUR SOLAR SYSTEM INVOLVES TREMENDOUS DISTANCES. SHOWN ABOVE ARE DISTANCES OF THE PLANETS FROM THE SUN IN MILES.

frequency of a signal transmitted from the spacecraft and the frequency as it is received on the ground, which is proportional to the radial velocity between the Earth and the spacecraft.

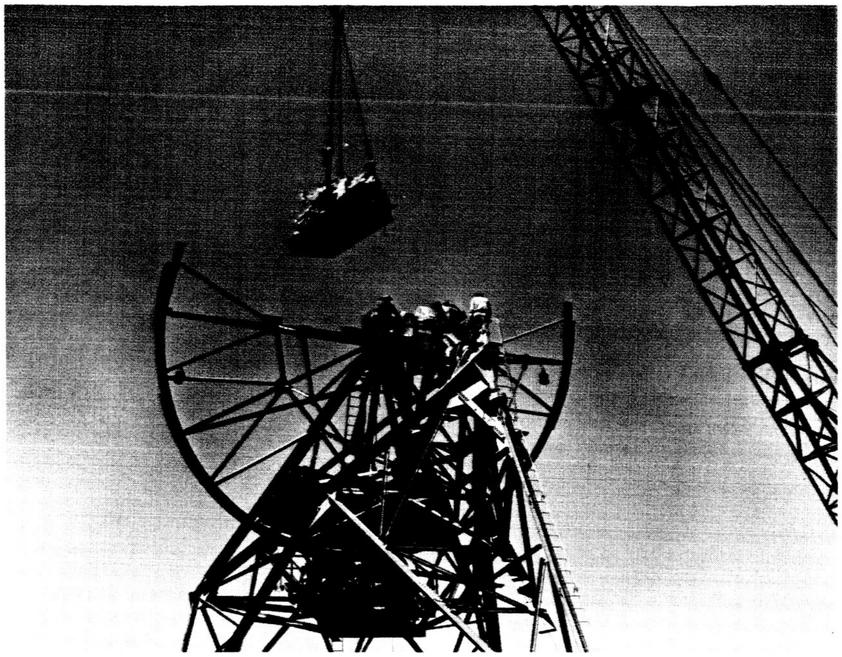
Because of inexact knowledge of the transmitted frequency, the accuracy of the measurement of spacecraft velocity using one-way doppler is limited to about 90 feet per second. Two-way doppler developed for the DSIF has increased this accuracy to better than one inch per second. In two-way doppler, a signal is transmitted from the ground to a turn-around transponder (receiver–transmitter) on the spacecraft, where it is converted to a new frequency in an exact ratio with the ground frequency, and then retransmitted to the ground. Since the frequency of the signal sent from the ground can be determined with great precision, the resulting doppler information and velocity calculations are very accurate. By two-way doppler calculations alone the position of a spacecraft at a distance of several million miles can be determined within 20 to 50 miles. A JPL-developed electronic ranging system uses an automatic coded signal in conjunction with doppler information to provide range measurements with an accuracy better than 45 feet at lunar and planetary ranges.

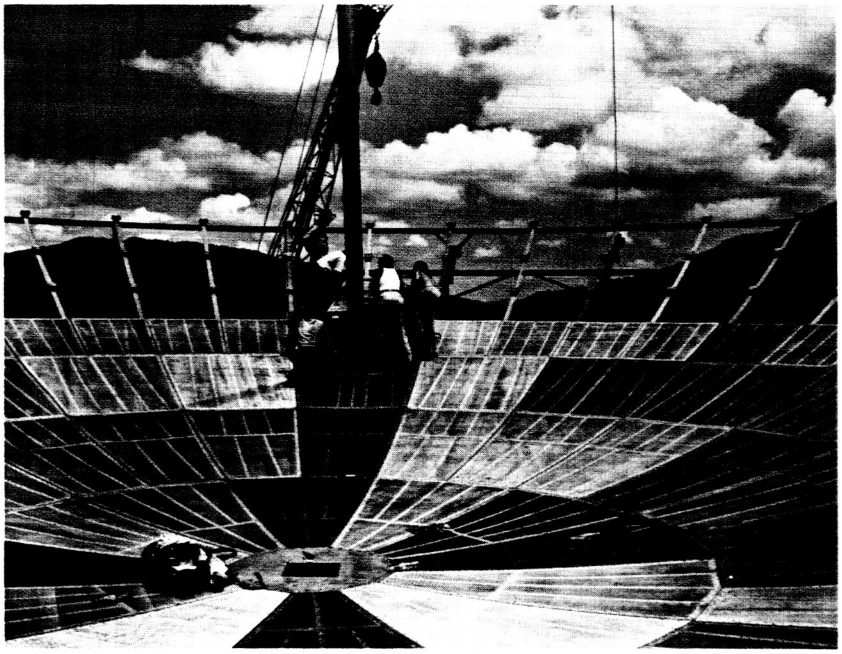
Because of the doppler shift and other effects, the frequency of the signal received on the ground from the spacecraft varies widely, which means that receiver tuning must be continually changed. Both spacecraft and DSIF ground receivers use a phase-lock method of signal detection, which maintains an automatic frequency control and keeps the receiver locked in tune with the received frequency.

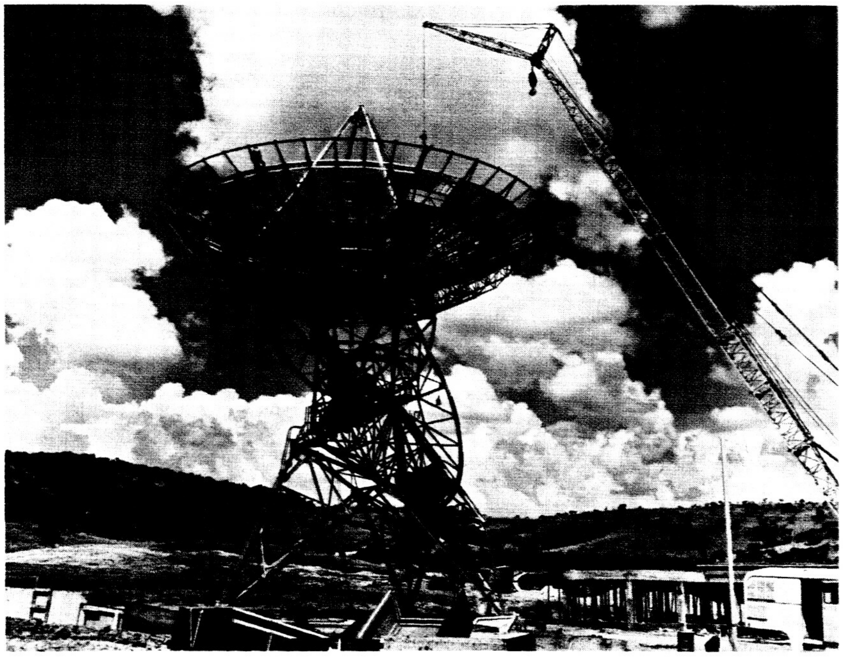
Receiver performance is measured by the ability to pick up the weak signal from the spacecraft transmitter and separate it from surrounding noises (static) originating not only in the Earth's atmosphere, but from lunar, solar and galactic sources. DSIF receivers have a very low threshold—the point at which the receiver can no longer detect the signal, just as in human hearing, the lower limit at which the ear no longer responds to a sound is the threshold of hearing. And just as internal body sounds (such as that of blood coursing through the head) interfere with the lowest external sound discernible to the human ear, radio receiver sensitivity is affected by internal electronic noise in the system itself. To help overcome this problem, advanced methods of ultra-low-noise signal amplification have been developed. DSIF S-band receiving systems use a traveling-wave maser amplifier. The maser is basically a synthetic ruby crystal immersed in liquid helium to keep it at a very low temperature and operates with a "pumped-in" source of microwave energy to augment the strength of the incoming signal without generating much internal system noise.

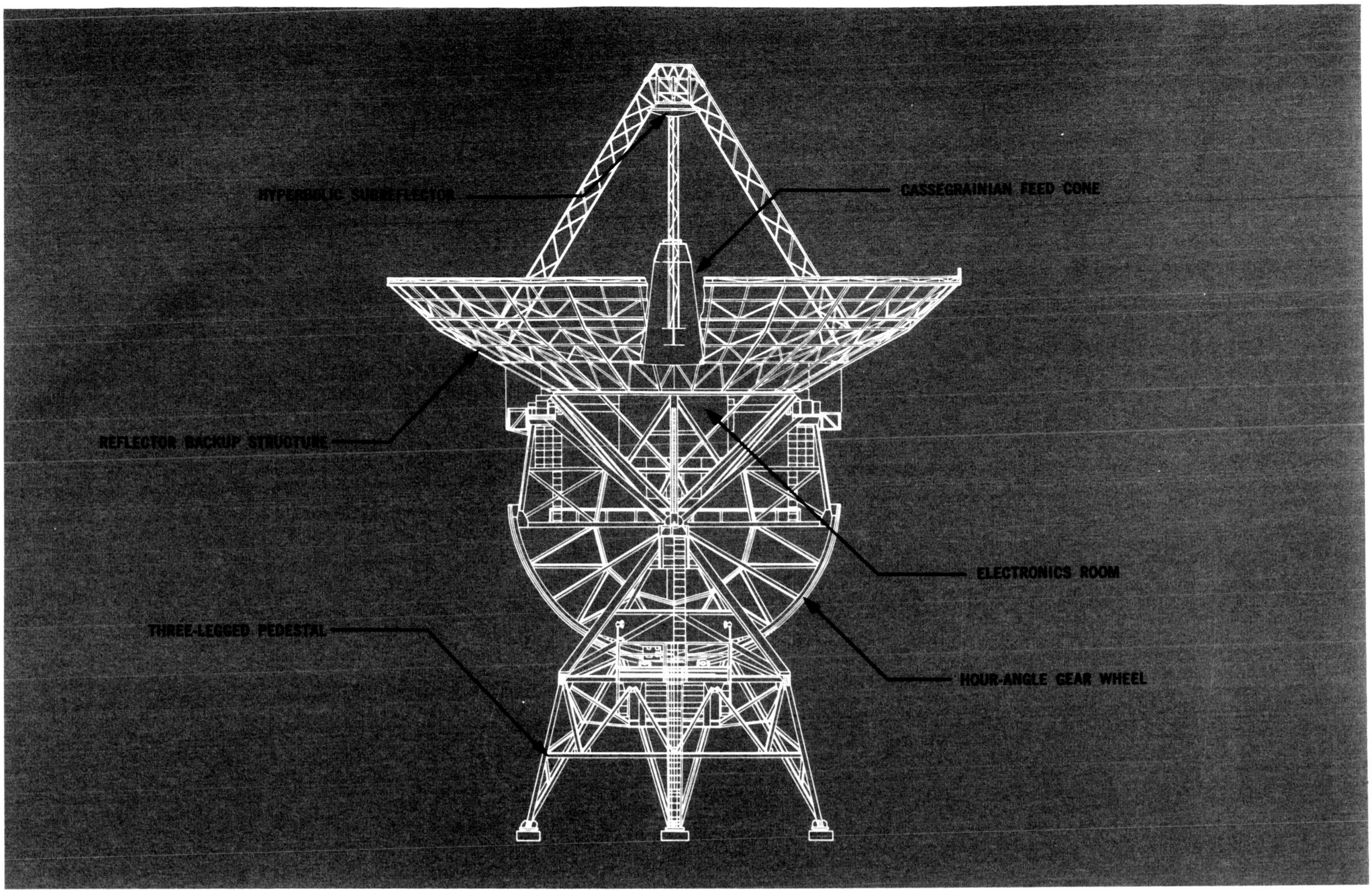
The basic components of the spacecraft communications systems in the DSIF are essentially the same, although auxiliary equipment may vary depending upon the special requirements for scheduled missions. The following pages describe the system installed at Johannesburg. The complete system comprises thousands of different elements which must work perfectly under precision requirements.

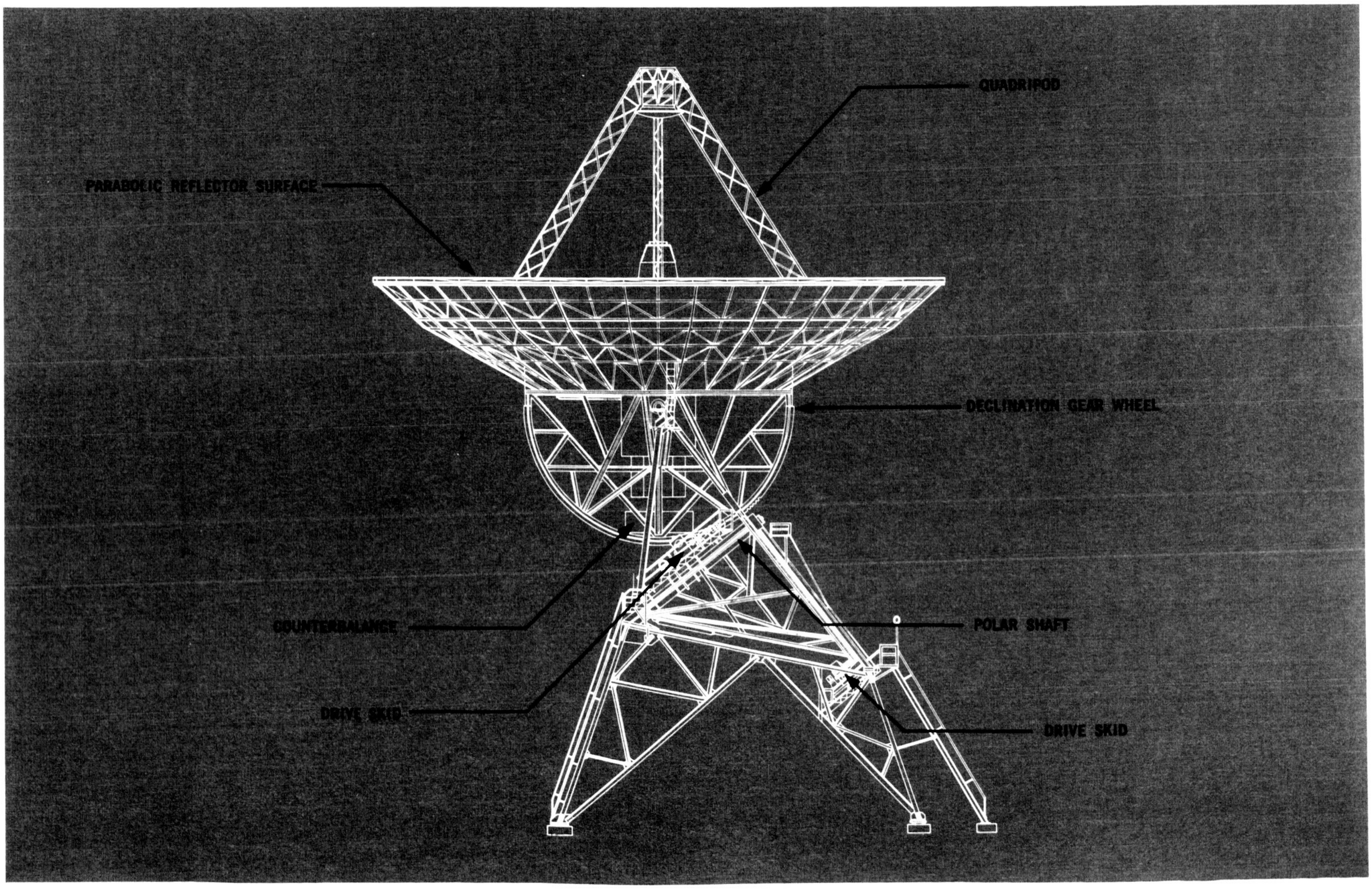
Construction of the Johannesburg Station was started in 1960. Early photographs show stages of erection of the 85-foot-diameter antenna.








HYPERBOLIC SUBREFLECTOR
CASSEGRAINIAN FEED CONE
REFLECTOR BACKUP STRUCTURE
ELECTRONICS ROOM
THREE-LEGGED PEDESTAL
HOUR-ANGLE GEAR WHEEL


QUADRIPOD
PARABOLIC REFLECTOR SURFACE
DECLINATION GEAR WHEEL
COUNTERBALANCE
POLAR SHAFT
DRIVE SKID
DRIVE SKID

FACING: *Two views of the basic DSIF antenna with an 85-foot-diameter reflector display the intricate balance of its structural steel ribs and girders. Antenna and supporting structure are as tall as a 10-story building, and weigh about 600,000 pounds.*

The Antenna

The standard DSIF antenna uses a parabolic reflector, 85 feet in diameter. The reflector is a perforated metal mirror that looks like an inverted umbrella and is often called the "dish." The antenna and its supporting structure stand 10 stories high and together weigh around 600,000 pounds.

About 8,000 pounds of electronic and operating equipment are an integral part of the antenna structure. This equipment is mounted on the antenna itself and in rooms reached by ladder on the supporting structure. The supporting base is a reinforced concrete pad sunk deep into the ground. Whenever equipment is added or moved, counterbalancing weights must also be adjusted to distribute stress evenly over the structure.

Driving the Antenna

The 85-foot-diameter antenna is steerable; that is, its "beam" or major radiation pattern can be readily shifted in any direction to follow the spacecraft. When a deep space probe gets out and away from the Earth, it travels in an orbit or path similar to other celestial bodies, and "rises" and "sets" on the horizon like the Sun. The predicted or actual course of a spacecraft is determined by the same methods astronomers use in locating heavenly bodies. That is, the angular position of the spacecraft relative to the star background is defined by a set of imaginary circles (coordinates) corresponding somewhat to Earth longitude and latitude. Each antenna in the DSIF is oriented to a set of local coordinates that are used to measure the antenna-pointing angles by which the spacecraft is located. The DSIF tracking antennas use a system of polar coordinates which measure the hour angle (representing angular direction referenced to a station's local meridian circle) and the declination angle (representing angular direction referenced to the celestial equatorial circle).

The gear system that moves the antenna is polar-mounted. The axis of the polar, or hour-angle gear wheel, is parallel to the polar axis of the Earth. This gear sweeps the antenna in an hour-angle path from one horizon to the other. The declination gear wheel, which pivots the antenna dish up and down, is mounted on an axis parallel to the Earth's equator. These wheels can be moved either separately or together. The arrangement of the gears allows the beam of the giant reflector to be pointed in almost any direction in the sky.

The motion of the antenna is controlled by the servo system, which consists of hydraulic pumps and motors, gear reducers, and pinions that engage the antenna gear system. Separate servo systems drive the polar wheel and the declination wheel. Electric-motor-driven pumps in the hydro-mechanical building send high-pressure hydraulic fluid through stainless steel pipes up to the driving motors on the antenna that actuate the gears. The electronic control and readout equipment for positioning the antenna is in a separate control room. Like the

FACING, TOP: *The polar-mount antenna is so-named because the axis of the main gear wheel, or polar wheel, is mounted parallel to the Earth's polar axis. Axis of the declination wheel is parallel to the Earth's equator.*

FACING, BOTTOM: *Close-up view of the polar mount gear system of the 85-foot antenna shows the large polar wheel and smaller declination wheel which are rotated to steer the antenna in the direction of the spacecraft as it moves across the sky.*

driver of an automobile, the operators of the servo system control and operate the equivalent elements — steering wheel, brakes, clutches, etc. — and in the same sense "drive" the antenna. They are responsible for the safety and efficiency of its operation, and the safety of personnel who might be working on the antenna.

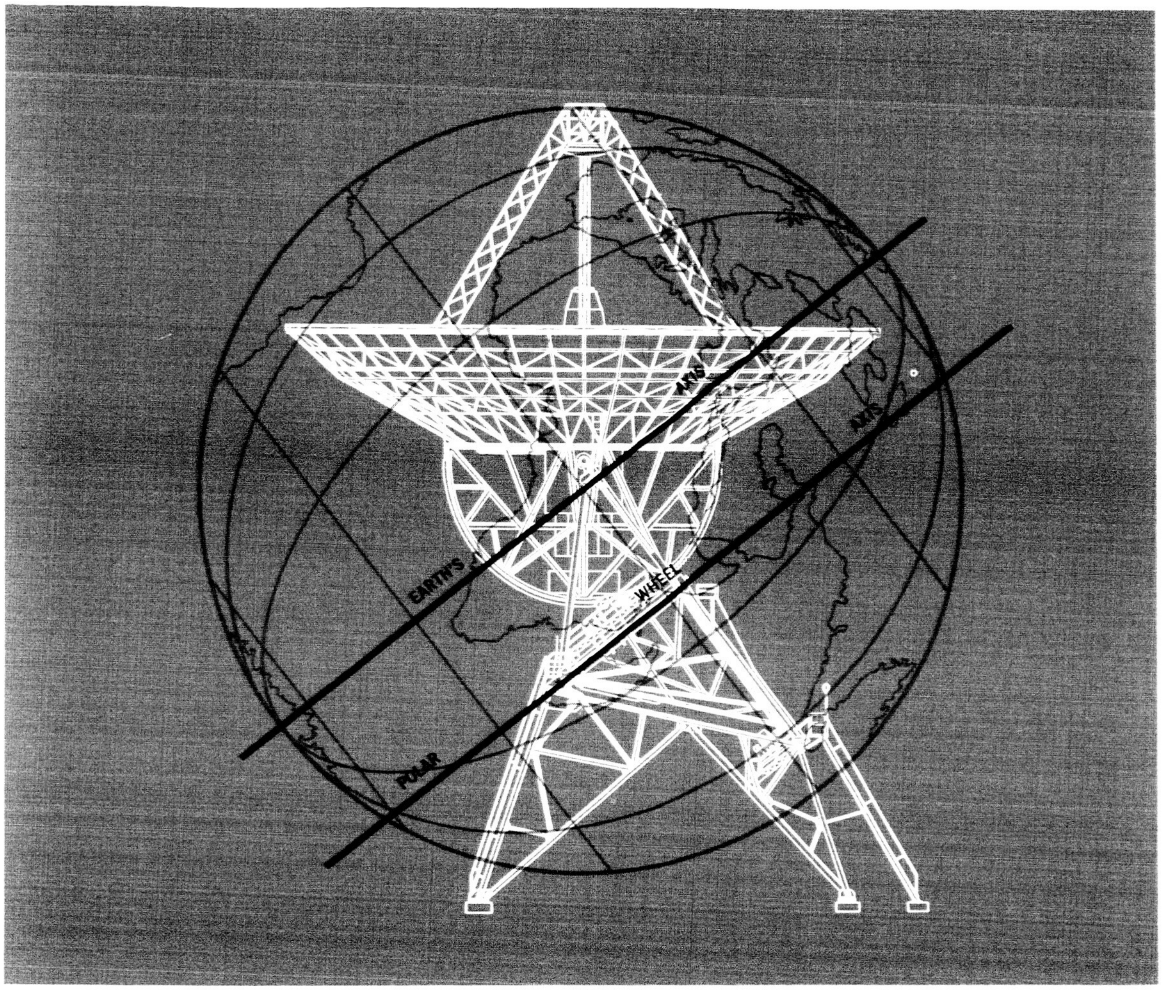
Pointing the Antenna

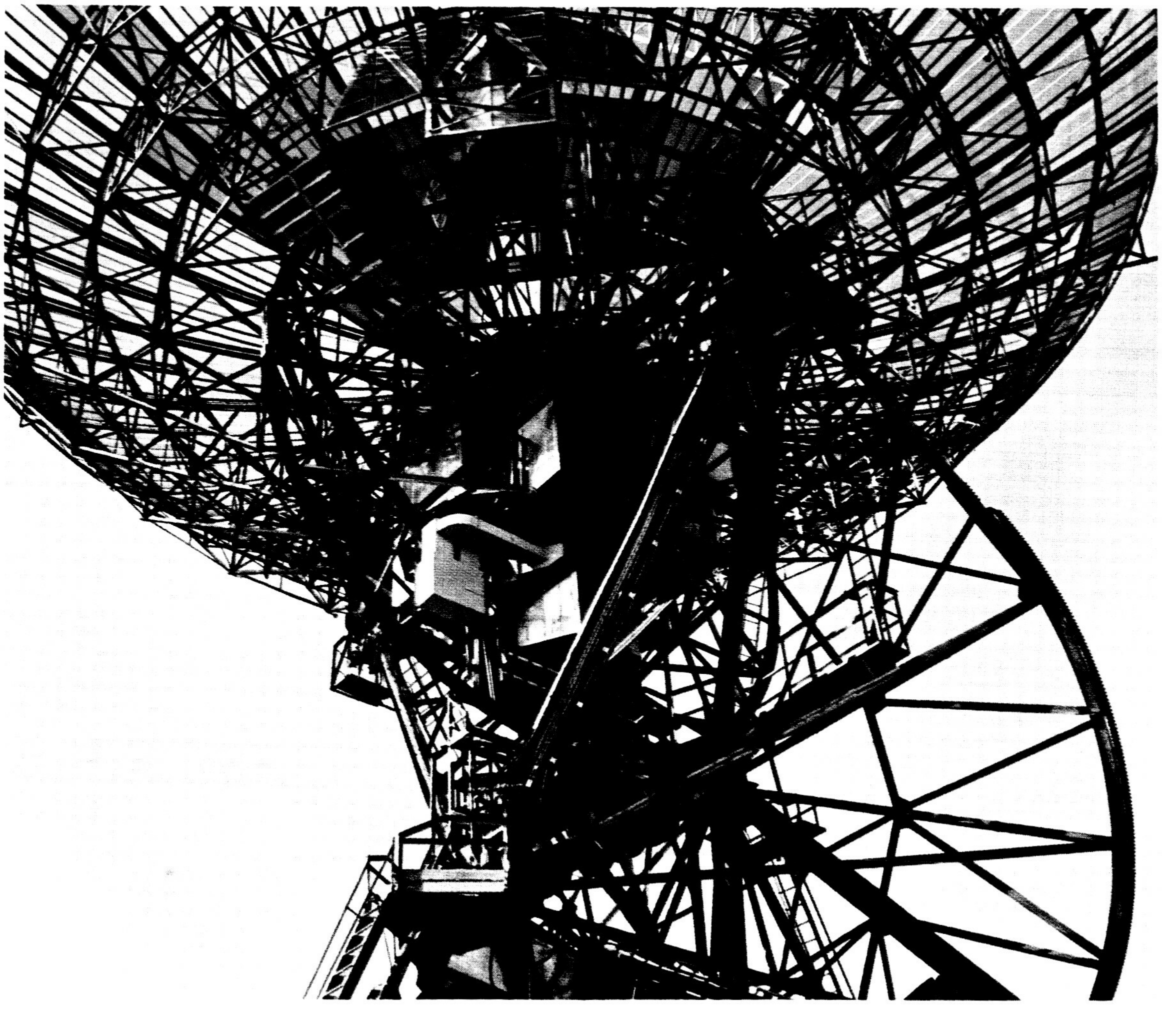
The antenna, like an ear trumpet, receives most strongly the signals coming from a point directly in front of it. Therefore, it is necessary to keep the antenna pointed in the direction of the space vehicle to receive its signals. To accomplish this, the servo system of the Johannesburg tracking station normally operates in what is called a slave mode: angle information for pointing the antenna at specific times is supplied to the station by computer printout from the JPL Space Flight Operations Facility (SFOF) control center in Pasadena, and the computer and the antenna servo system operate together in an automatic loop to keep the antenna trained on the spacecraft as it moves across the sky.

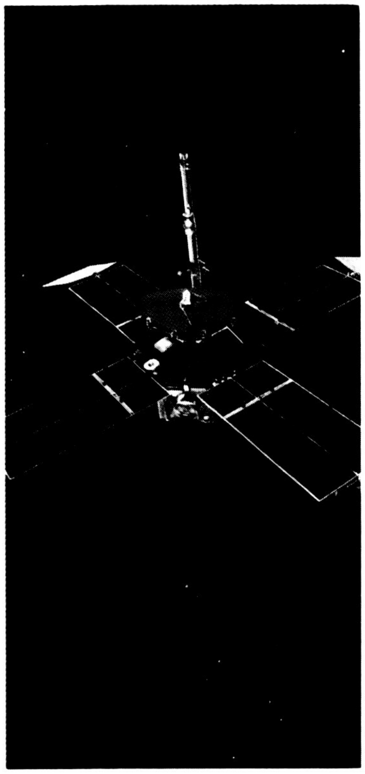
Pointing-angle information based on computer-calculated predicted trajectory data may be supplied to the station in advance of the actual launch of the spacecraft, and is then verified by actual trajectory data from early passes over the DSIF sites, particularly first-acquisition data from Johannesburg or Ascension Island. Computer angle information may also be verified at Johannesburg by nulling error signals from the receiver angle-tracking channels. (Error signals are voltages that tell the angle between the spacecraft and the exact center of the beam of the antenna.) With accurate information on the time and position at which the spacecraft will appear in the antenna field of view, no time is lost in locating the spacecraft.

Aligning the Antenna

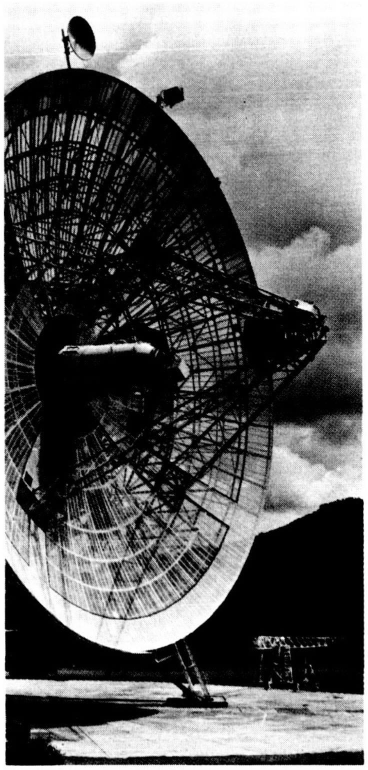
The gears and all parts of the antenna structure are so precisely balanced and aligned that, heavy as it is, the antenna can be rotated at rates up to 1 degree per second. The Johannesburg station has a collimation tower, located about two miles from the antenna, which is used in testing and adjusting antenna alignment and operation. A test antenna, a transmitter–receiver unit, and optical targets are mounted on the collimation tower. The tower simulates spacecraft signals for testing antenna and station operation. Visual checking of antenna boresighting (adjusting the line of sight, similar to aligning gun sights) is done in conjunction with an optical tracking package, mounted on the 85-foot antenna, which consists of a television camera, a 35-mm film boresight camera, and an optical telescope. This equipment may also be used for optical tracking of luminous celestial objects such as the Moon, planets, and stars. Radio stars of known position are also tracked by the antenna to verify pointing accuracy and other performance factors.


EARTH'S AXIS
POLAR AXIS
WHEEL

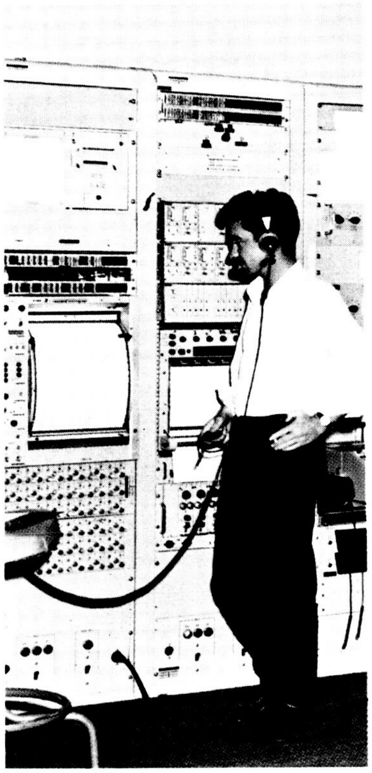




1. *Engineering measurements and scientific data generated by instruments aboard the spacecraft are radioed to Earth by the spacecraft transmitter.*



2. *The radio signal, greatly reduced in strength because of the distance it travels, is captured by the Earth antenna.*



3. *The signal is amplified and processed through the receiving system, and information from the signal is translated and recorded on magnetic and punched paper tape.*

4. *Data gathered at the Johannesburg Station are transmitted to the SFOF at JPL by teletype and high-speed digital data lines.*

5. At the SFOF control center, information is processed by computers into usable form for analysis by scientists and engineers.

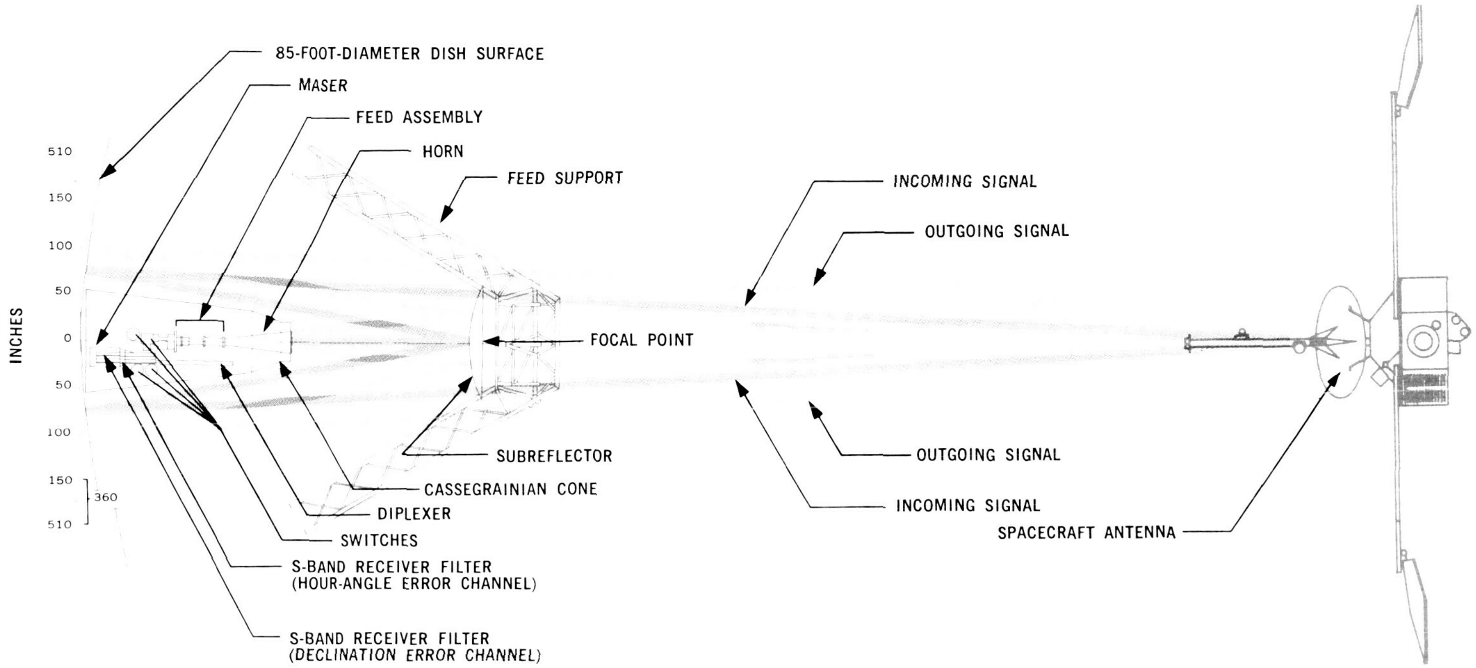
6. Processed data present video, tracking, engineering, and scientific telemetry in the form of time-labelled numerical printouts or graphs. All processed data are stored on magnetic tape.

Tracing a Signal Received From the Spacecraft

The reflecting surface, or dish, of the 85-foot antenna collects the radio energy which is fed into the sensitive DSIF receivers. The antenna, with an area of almost 6000 square feet, can detect signals so faint that the radio-frequency energy is calculated to be about equivalent to that radiated by a 1-watt light bulb at a distance of approximately 75 to 80 million miles.

In general, shorter radio-frequency connections between the antenna signal feed system and the receiver mean greater antenna efficiency. DSIF antennas for S-band operation have a Cassegrainian cone feed system mounted at the center, or focal point, of the reflector, which allows very short connections. This system is similar in design to that of a Cassegrainian telescope used in optical astronomy. Radio waves collected by the main dish bounce up and hit a subreflector mounted on a truss-type support that extends about 36 feet from the center of the dish. The subreflector focuses the waves into a feed horn in the Cassegrainian cone. The signal is then fed directly from the feed horn to the low-noise maser amplifier, so that maximum amplification of the weak signal occurs before it is contaminated by the electronic noise of the rest of the receiver system.

The S-band phase-lock receiver has four separate receiving channels: two reference channels (called sum channels) for doppler information, spacecraft telemetry, and TV signals; and two channels that carry angle-tracking signals for antenna pointing. The information in each of the sum channels is dispersed by distribution amplifiers in the receiver system to proper destinations in the telemetry instrumentation and data-handling systems in the control room.



THE CASSEGRAINIAN FEED SYSTEM IS THE FOCAL POINT FOR RECEIVING AND SENDING SIGNALS. THE DIAGRAM SHOWS HOW OUTGOING AND INCOMING RADIO WAVES TRAVEL BETWEEN THE GROUND ANTENNA AND SPACECRAFT ANTENNA.

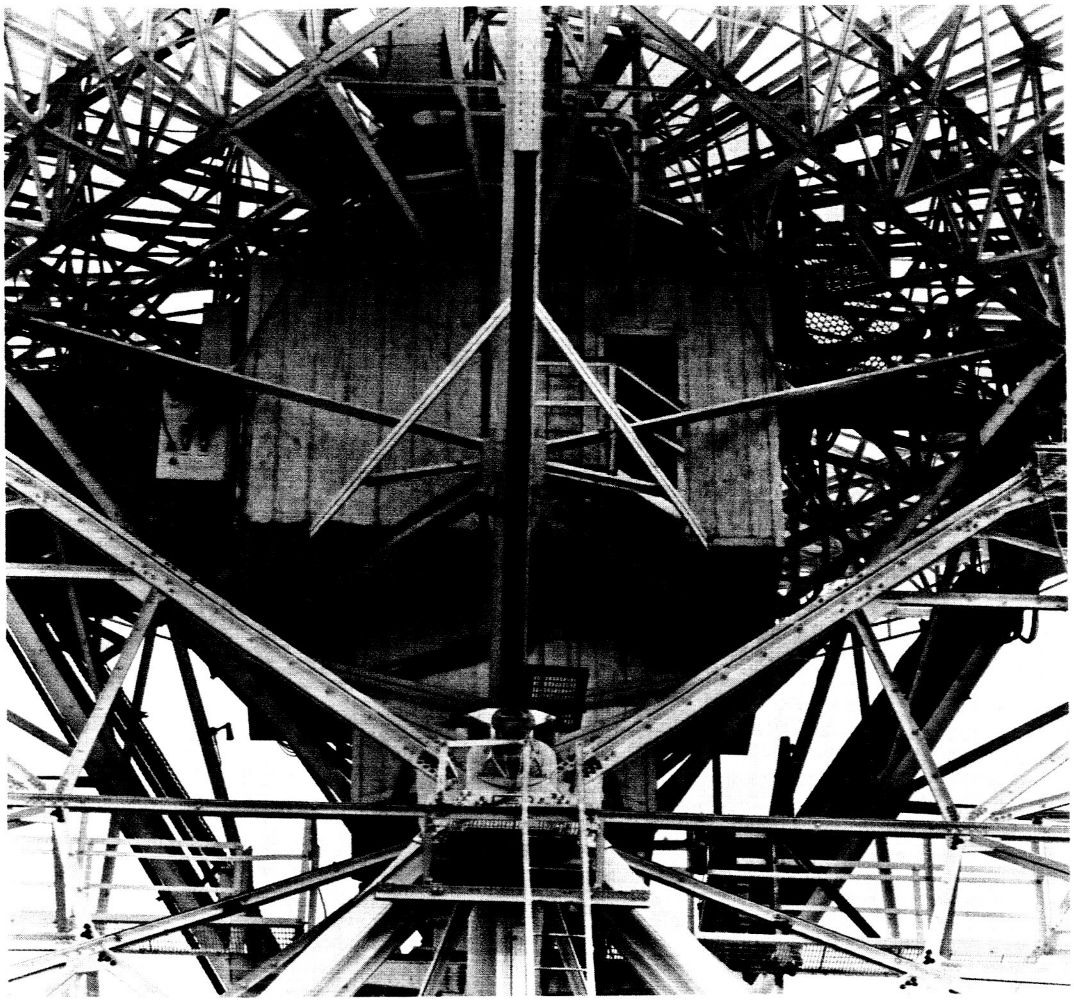
Sending a Command to the Spacecraft

Changes to the trajectory of a deep space probe are controlled by transmitting command signals that initiate roll, pitch, and yaw maneuvers, as well as propulsion, ignition, and timing sequences. The appropriate commands to be sent to a spacecraft are determined by computations made from tracking data. Signals are also sent to the spacecraft to change data rates, change the type of telemetry information being transmitted, turn the transmitter on or off or change its power, reorient the spacecraft or its antennas, or even to switch antennas, receivers, and transmitters.

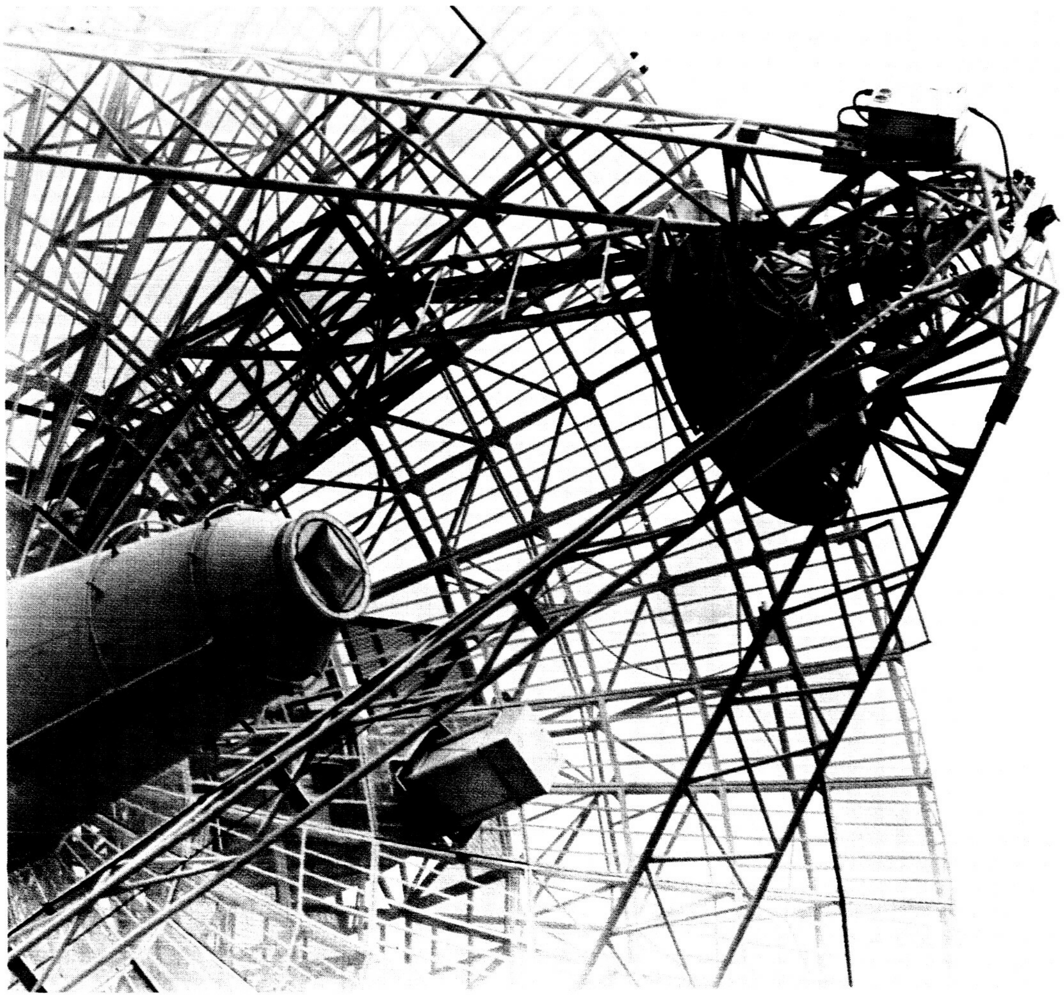
Sending a command to the spacecraft is somewhat the reverse process of receiving a signal. The transmitting station is equipped with a 10-kilowatt transmitter. The exciter and controls of the transmitter are in the control room; the radio-frequency power amplifier and associated equipment are mounted up on the antenna. The power level of the signal produced by the exciter is very low—on the order of a few watts. This is amplified in the power amplifier so that the signal radiated from the antenna is very strong—at least 10,000 watts. The transmitter is normally used with a diplexer, which is a device designed to allow simultaneous operation of both transmitter and receiver at different frequencies on a single antenna and feed system.

The commands to be sent to the spacecraft originate in the JPL SFOF control center in Pasadena. Command information is sent over the teletype link from Pasadena to the station at Johannesburg.

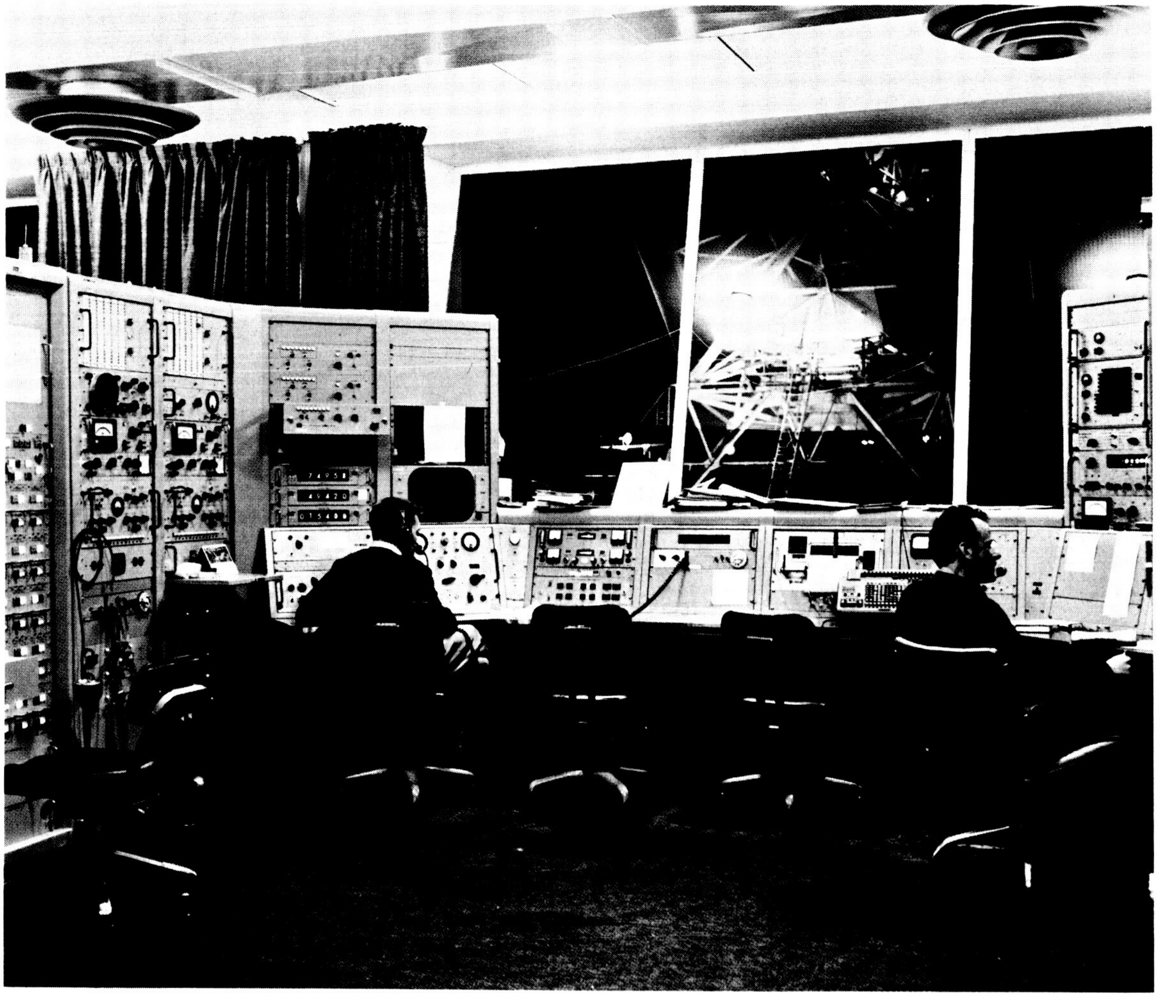
Because an incorrect command could result in possible damage to the spacecraft, extreme precautions are taken to ensure accuracy. Command information from the SFOF is usually sent three separate times over the teletype links to the command station, and is also verified by voice over the telephone. Ground command and control equipment at the station includes read-write-verify equipment that carefully checks a command before it is sent and as it is being sent to the spacecraft. This special equipment reads and verifies the teletype message, transforms the command into a signal for radio transmission, and monitors the transmitted radio-frequency signal bit-by-bit. If any bit proves incorrect, transmission is automatically stopped to make correction. Very often, especially if the command is to be stored in the spacecraft memory equipment for later execution, the command as received by the spacecraft is telemetered back to the ground and checked again with the transmitted command. A special-purpose computer is used just to execute these check routines.



The 10-kilowatt transmitter, which gives an effective radiating power of 2.5 billion watts for sending signals into space, is located in the electronics room on the antenna.



Cassegrainian feed cone is mounted in the center of the antenna reflector. At lower right of the cone is the acquisition aid antenna.



FACING, TOP: *Center of operations at Johannesburg is the control room. Consoles lining the walls contain the controls for the receiver, transmitter exciter, and servo system, and the ground instrumentation and data-handling equipment.*

FACING, BOTTOM: *At the SFOF center in Pasadena, data gathered by the DSIF are used by engineers in space flight control operations and analysis of mission results.*

Translating the Information From the Spacecraft

Signals processed by the receiver are sent to ground instrumentation and data-handling equipment in the control room. This includes paper-tape and magnetic-tape recorders, and ultraviolet oscillographs.

Tracking-data-handling equipment records angle measurements of antenna position, doppler frequency measurements, range measurements, and time. These data are recorded on paper tape for immediate teletype transmission to the SFOF in Pasadena for use in spacecraft orbit determination, calculation of maneuver parameters, command decisions, and prediction of arrival time at the target.

Telemetry signals from the spacecraft that come in on the receiver sum channel are either time- or frequency-multiplexed or both; that is, the signals from the various measuring instruments on the spacecraft are carried on one composite radio-frequency signal, either sequentially (time-multiplexed) or simultaneously on several subcarrier frequencies (frequency-multiplexed). This composite signal is "unscrambled" by demodulators in the ground telemetry system. Analog or digital (or both) methods of signal modulation are used for transmission of data from the spacecraft to Earth.

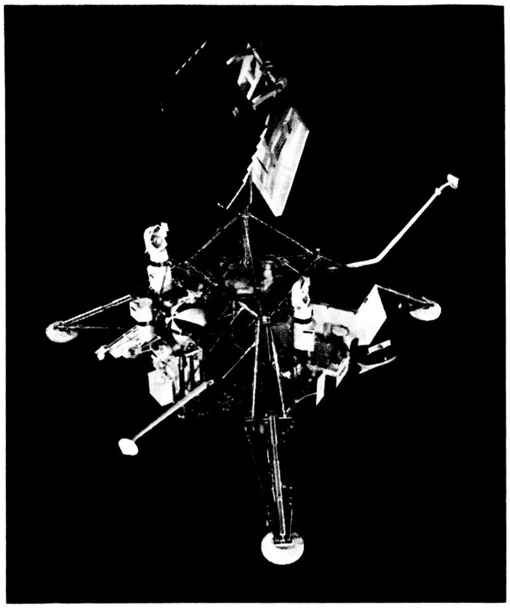
Analog modulation transmits engineering measurements in continuously varying electrical signals that represent measurements of voltages, temperatures, pressures, radiation intensity, etc. With coded digital modulation techniques, it is possible to increase the efficiency of data transmission from the spacecraft. Digital transmission also simplifies data handling at the ground station because digital signals can be formatted for direct inputs to computers and for teletype transmission.

The detected unscrambled signals are recorded on magnetic tape so that complete permanent recordings of all telemetry data from the spacecraft will be available for later data processing either at the SFOF or by the NASA Center responsible for the project. Certain selected spacecraft telemetry signals are displayed at the station as they are received for the use of operating personnel in maintaining contact with the spacecraft.

In addition to processing and recording spacecraft telemetered data, the station also processes and records data generated by the ground equipment, such as received signal strength, transmitted power, and condition of all station equipment. This information is processed by the digital instrumentation system, which uses general-purpose digital computers that accept and process both analog and digital signals.

All taped information sent to JPL is labeled and identified by date, time received, station, and spacecraft number. Because time reference is a critical factor in tracking determinations, and in other DSIF functions that depend upon the timing of electronic phenomena, the time of receipt of telemetry data is recorded to an accuracy of at least one hundredth of a second. All data received during a mission are recorded on magnetic tape for a permanent record and for the use of scientists and engineers in evaluating the results of a mission. Literally hundreds and hundreds of miles of magnetic tape are used in some missions, and final evaluation takes months, and sometimes years, of study.

DSIF acquisition procedures, which include antenna pointing, receiver tuning, transmitter tuning, ranging lock, and telemetry decommutation, are so precisely timed and coordinated that it is possible to start recording data from 1 to 10 minutes after radio contact with the spacecraft is established, and to start transmitting data to the SFOF within 4 to 16 minutes.



SURVEYOR: *Mission—lunar soft-landing to make surface analysis experiments and to take TV pictures.*

DSN Mission Support

In preparation for increasingly accelerated activities in space, the Deep Space Network has developed the capability of controlling operations of as many as four spacecraft in flight at the same time, and advanced communication techniques that make the prospect of probes to planets as far out as Jupiter within the realm of possibility.

The DSN supports the following space exploration projects for which JPL is responsible:

Surveyor. A soft-landing of instrumented craft on the Moon capable of performing operations to contribute new scientific knowledge about the lunar surface and to make final tests in support of the *Apollo* program.

Mariner. A flyby mission to Mars during the 1964–1965 Mars opportunity to take TV pictures of the planet's surface, make radiation and magnetic fields and particles experiments, and provide basic knowledge of spacecraft performance in long-duration flights to interplanetary distances.

Voyager. An advanced mission that will send unmanned spacecraft to conduct scientific exploration of the planets, beginning with Mars in 1971.

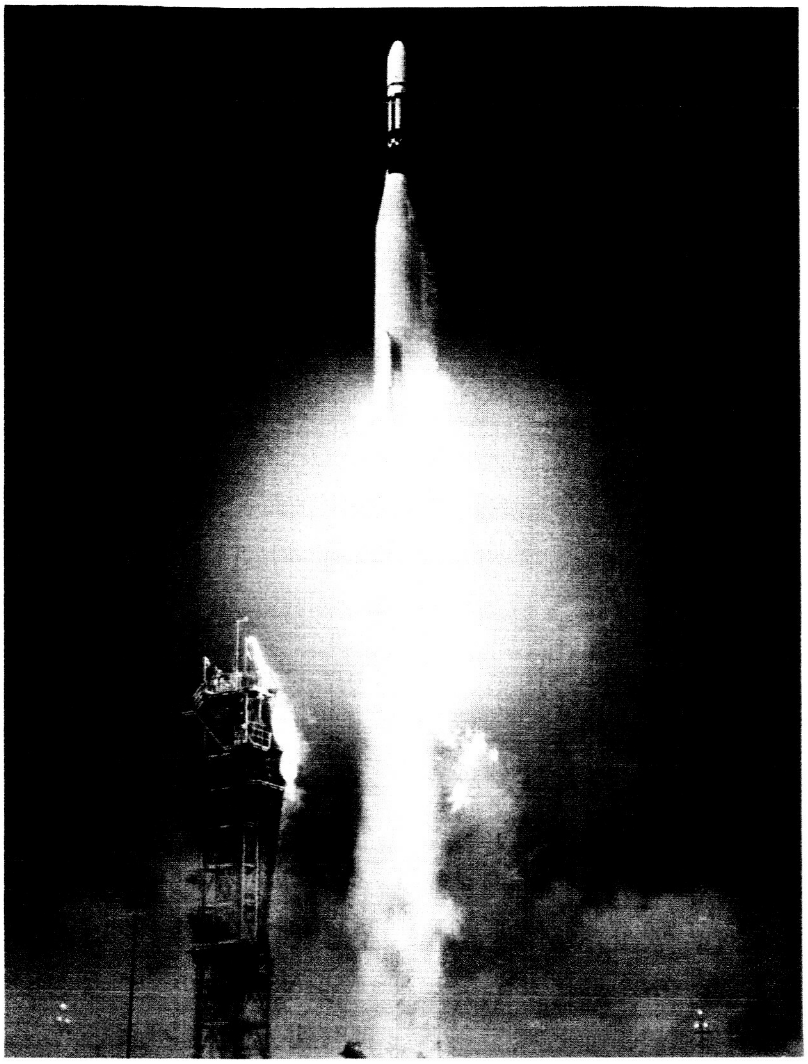
The DSN also supports the following missions for which the NASA agency identified with each is responsible:

Lunar Orbiter (Langley Research Center). A photographic mission to take pictures of the lunar surface from a satellite spacecraft.

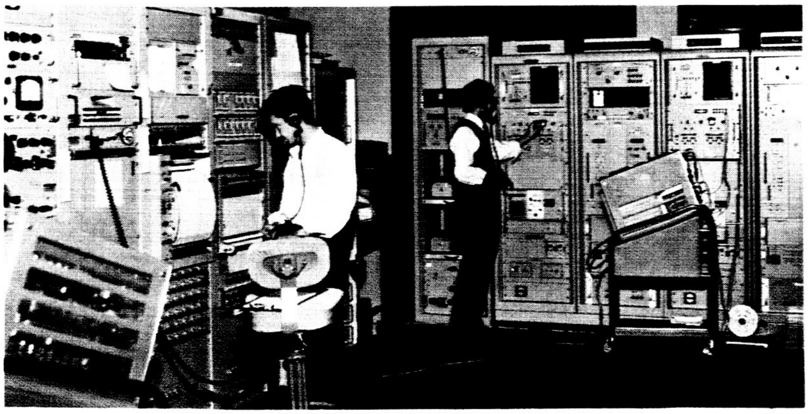
Pioneer (Ames Research Center). A series of probes designed to penetrate deep into our solar system to learn more about the nature of solar flares and other deep space phenomena.

Apollo (Manned Spacecraft Center). The manned spacecraft mission that will put men on the Moon.

As new programs are conceived to extend man's knowledge outward to the edges of the solar system, the Deep Space Network will be prepared to continue as the radio link with these 20th century explorers.



Mariner IV, boosted by an Atlas-Agena rocket, is launched from Cape Kennedy on its 7½-month journey to investigate the planet Mars at close range.



Control room at Johannesburg receives telemetry signals from Mariner IV.

Frame number 11, one of the most remarkable in the Mariner IV sequence of close-up pictures of Mars, shows large craters similar to those on the Moon.

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